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Theory of movement of the combined seeding unit

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Abstract

Modern energy-saving technologies, that are widely implemented currently in agriculture include the use of combined units that can not only reduce the agronomic timing of field work, but also reduce water loss by reducing the inter-operational periods of time, to reduce the impact of sealing machine units on the ground, to save fuel − materials and so on.

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Keywords: energy-saving; combined units; combined seed drill; power scheme; trailer combined sowing unit.

1. Background and means for solving the problem

We have developed and successfully tested in the field work of combined machine. It consists of a tractor and a combined seed drill, to which applicator fertilizer and seeder are connected. Operation of such dynamic systems requires high quality rectilinear motion during the manufacturing process and, consequently, the stability of its movement.

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The study of complex combined agricultural machine units is possible on the basis of the constructed mathematical models for this, including mathematical models of plane-parallel motion. Methods for constructing such machine units are well represented in the works from Vasilenko (1954), Vasilenko (1952), Vasilenko (1996), and Vasilenko (1965). In this case, the main type of movement of agricultural machine (trailed, mounted and self-propelled) is their plane-parallel motion, because this type of motion is determined by the quality of performing the specified processes. Study of combined agricultural machine units and work aggregates are determined by many already published scientific papers and some still in press from Vasilenko (1965), Bulgakov (2007), Guskov (1988), Timofeev (1965) and Adamchuk (2015). Numerous studies have found that the agronomic, operational and technical performance of the combined tractor units depends largely on the nature of their plane-parallel motion. Therefore, the study of plane-parallel motion of various agricultural machine units is necessary when evaluating existing and the design of innovative combinations of such units Vasilenko (1996).

2. The solution of the problem

In order to study the complex plane-parallel motion of combined machine units it is necessary to build their mathematical models, create differential equations of plane-parallel motion that will eventually allow to find a rational design and kinematic parameters of the sustainability of movement of machine, and, consequently, the quality of the process. Therefore, we first develop a power scheme of trailer combined sowing unit, which consists of aggregated tractor 1, to which is attached the fertilizer distributing drill 2, which produces a stripe of mineral fertilizers, behind which, with the help of the hitch 3 a grain seeder 4 is attached (see Fig. 1).

$$\left.\begin{aligned}
&m_1\ddot{x}_1+\sum_{i=2}^{4}m_i\ddot{x}_i=\sum_{i=1}^{4}F_{xi},\\
&m_1\ddot{y}_1+\sum_{i=2}^{4}m_i\ddot{y}_i=\sum_{i=1}^{4}F_{yi},\\
&I_1\ddot{\beta}_1+\left(l_1-a_1\right)\sum_{i=2}^{4}m_i\left(\ddot{x}_i\sin\beta_1-\ddot{y}_i\cos\beta_1\right)=\\
&=M_{C_1}-M_{rf1}+\left(l_1-a_1\right)\times\\
&\times\left[\sin\beta_1\sum_{i=2}^{4}F_{xi}-\cos\beta_1\sum_{i=2}^{4}F_{yi}\right],\\
&I_i\ddot{\beta}_i+m_ia_i\left(\ddot{x}_i\sin\beta_i-\ddot{y}_i\cos\beta_i\right)+\\
&+l_i\sum_{j=i+1}^{4}m_j\left(\ddot{x}_j\sin\beta_i-\ddot{y}_j\cos\beta_i\right)=\\
&=M_{O_i}-M_{rfi}+l_i\left(\sin\beta_i\sum_{j=i+1}^{4}F_{xj}-\right.\\
&\left.\quad-\cos\beta_i\sum_{j=i+1}^{4}F_{yj}\right),\qquad\left(i=\overline{2,4}\right).
\end{aligned}\right\}\tag{1}$$

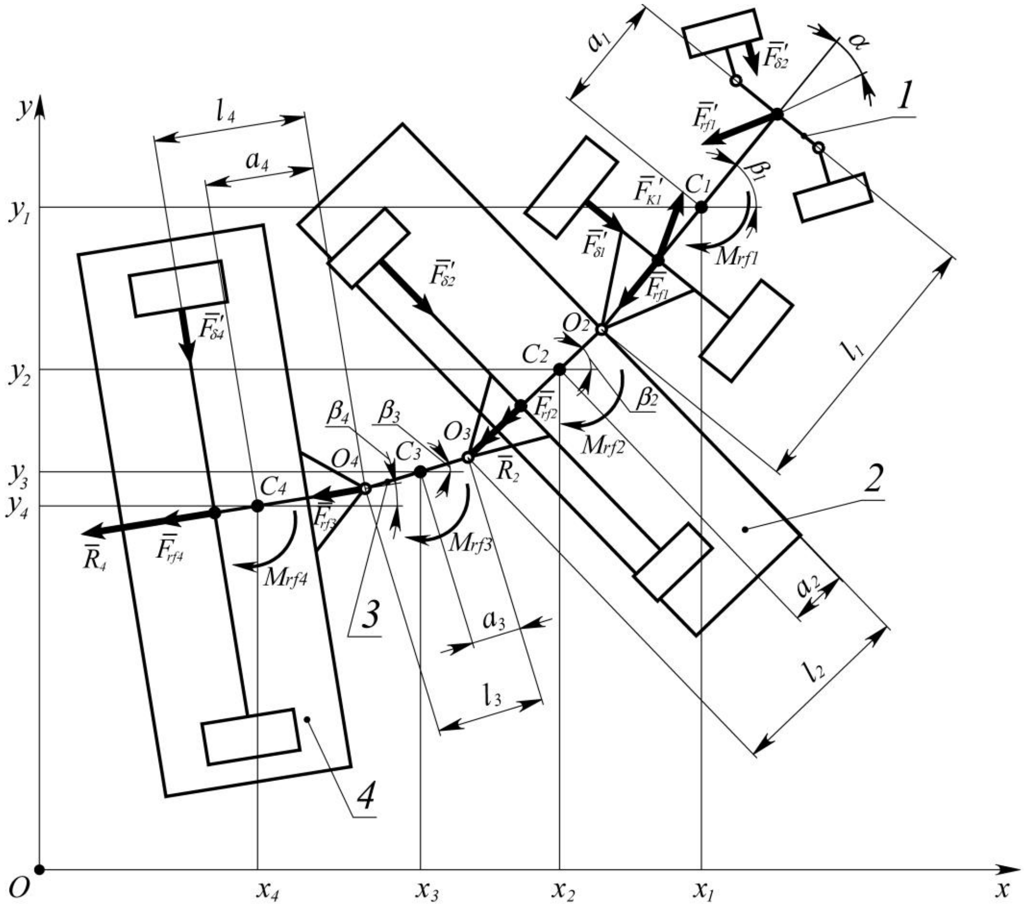

Fig. 1. Power scheme trailer combined unit: 1 – tractor, 2 – fertilizer distributing seeder, 3 – hitch, 4 – grain seeder

In this case, the first three equations in (1) describe the linear motion of the center of mass of the tractor the first three equations, along the axis $\boldsymbol{Ox}$ and $\boldsymbol{Oy}$ – $\boldsymbol{x_1}$and $\boldsymbol{y_1}$ and angular motion $\boldsymbol{\rho_1}$ around its center of mass. The fourth equation of system (1), written in general terms, describes the combined unit turns around the property of their centers of mass. Thus, the index i varies from 2 to 4 and define the actual twists: Mineral spreaders – $\boldsymbol{\rho_2}$, hitch – $\boldsymbol{\rho_3}$ and grain drill – $\boldsymbol{\rho_4}$.

For practical use of the system of differential equations (1) it is necessary to determine force factors that it contains.

Define further:

$$F_{rf\,i} = F^{l}_{rf\,i} + F^{r}_{rf\,i} = \\ = \frac{I_{ki}\left\{2\left[\ddot{x}_i\cos\beta_i + \ddot{y}_i\sin\beta_i + \dot{\beta}_i^2(l_i - a_i)\right] + \ddot{\beta}_i(d_{ri} - d_{li})\right\}}{r_{ki}^2}. \tag{2}$$

We compute $\boldsymbol{M_{rfi}}$ – moment of resistance of rotation of i-level unit i-th as the sum of the moments of resistance forces: the resistance of the left and right wheels relative to the center of mass of the i-th link:

$$M_{rf\,i} = M_k(\bar{F}^l_{rf\,i}) + M_k(\bar{F}^r_{rf\,i}) = -F^l_{rf\,i}\,d_{li} + F^r_{rf\,i}\,d_{ri} = \\ = \frac{I_{ki}\left\{\left[\ddot{x}_i\cos\beta_i + \ddot{y}_i\sin\beta_i + \dot{\beta}_i^2(l_i - a_i)\right](d_{ri} - d_{li}) + \ddot{\beta}_i(d_{li}^2 + d_{ri}^2)\right\}}{r_{ki}^2}. \tag{3}$$

Rear drive wheels of the tractor depending (2) and (3), with the proviso that $d_{ri}=d_{li}=d_1$ will look like this:

$$F_{rf\,1} = \frac{2I_{k1}\left[\ddot{x}_1\cos\beta_1 + \ddot{y}_1\sin\beta_1 + \dot{\beta}_1^2(l_1 - a_1)\right]}{r_{k1}^2} - \frac{2M'_e}{r_{k1}}\ , \tag{4}$$

$$M''_{rf\,1} = 2I_{k1}\,\ddot{\beta}_1\left(\frac{d_1}{r_{k1}}\right)^2, \tag{5}$$

Where: $M'_e = \frac{M_e\eta}{2}$; M_e – torque that develops engine tractor; η – factor which takes into account the type of tractor transmission.

Define $\bar{F}'_{rf\,1}$ and $M'_{rf\,1}$ for the front steering wheels of the tractor.

From equation $F^l_{rf\,i} = \frac{I_{ki}\ddot{x}'_{li}}{r_{ki}^2}$ to have left wheel:

$$F'^l_{rf\,1} = \frac{I'_{k1}}{r'^2_{k1}}\cdot\ddot{x}''_1 = \frac{I'_{k1}\left\{\ddot{x}_1\cos(\beta_1-\alpha) + \ddot{y}_1\sin(\beta_1-\alpha) - \right.}{1}\times \\ \times\frac{-\ddot{\beta}_1\left[(d_1 + d_0\cos\alpha)\cos\alpha + (a_1 + d_0\sin\alpha)\sin\alpha\right] -}{1}\times \\ \times\frac{\left.-\dot{\beta}_1^2\left[(a_1 + d_0\sin\alpha)\cos\alpha - (d_1 + d_0\cos\alpha)\sin\alpha\right]\right\}}{\left(r'_{k1}\right)^2}, \tag{6}$$

Where r'_{k1} – the radius of the front wheels of the tractor; I'_{k1} – moment of inertia of the front wheels of the tractor relative to soybean rotation.

For the right wheel:

$$F'^r_{rf\,1} = \frac{I'_{k1}\left\{\ddot{x}_1\cos(\beta_1-\alpha) + \ddot{y}_1\sin(\beta_1-\alpha) + \right.}{1}\times \\ \times\frac{+\ddot{\beta}_1\left[\left(d_1 + d_0\cos\alpha\right)\cos\alpha + \left(a_1 - d_0\sin\alpha\right)\sin\alpha\right] -}{1}\times \\ \times\frac{\left.-\dot{\beta}_1^2\left[\left(a_1 - d_0\sin\alpha\right)\cos\alpha - \left(d_1 + d_0\cos\alpha\right)\sin\alpha\right]\right\}}{\left(r'_{k1}\right)^2}. \tag{7}$$

Taking into account (6) and (7) we obtain:

$$F'_{rf\,1} = F'^r_{rf\,1} + F'^l_{rf\,1} = \\ = \frac{2I'_{k1}\left\{\ddot{x}_1\cos\left(\beta_1-\alpha\right) + \ddot{y}_1\sin\left(\beta_1-\alpha\right) - \frac{1}{2}\ddot{\beta}_1 d_0 - \dot{\beta}_1^2\left[a_1\cos\alpha - \left(d_1 + d_0\cos\alpha\right)\sin\alpha\right]\right\}}{\left(r'_{k1}\right)^2}, \tag{8}$$

$$M'_{rf1} = M_k(\bar{F}''^{l}_{rf1}) + M_k(\bar{F}''^{r}_{rf1}) =$$

$$= \frac{2I'_{k1}\left(d_0 + d_1\cos\alpha\right)\left\{\ddot{\beta}_1\left[\left(d_1 + d_0\cos\alpha\right)\cos\alpha + a_1\sin\alpha\right] + \dfrac{\dot{\beta}_1^2 d_0 \sin\alpha\cos\alpha}{\left(r'_{k1}\right)^2}\right\}}{1}, \qquad (9)$$

Where M'_{rf1} – drag torque of the front steering wheels of the tractor, which is the sum of resistance to rotation torques of the left and right wheels relative to the centre of mass.

Taking into account (5) and (9) we obtain:

$$M_{rf1} = M'_{rf1} + M''_{rf1} = 2I_{k1}\ddot{\beta}_1\left(\frac{d_1}{r_{k1}}\right)^2 + \frac{2I'_{k1}(d_0 + d_1\cos\alpha)\times}{1}\times$$

$$\times\frac{\times\left\{\ddot{\beta}_1\left[\left(d_1 + d_0\cos\alpha\right)\cos\alpha + a_1\sin\alpha\right] + \dot{\beta}_1^2 d_0\sin\alpha\cos\alpha\right\}}{\left(r'_{k1}\right)^2}, \qquad (10)$$

Where M_{rf1} – moment of resistance of rotation of the wheels of the tractor.

The force $F'_{k1} = 0$, because it is included in the determination of force F_{rf1}. Numerical analysis of this task should be carried out using a PC.

3. Results and discussion

Thus, we find all analytical expressions for the force factors that compose the system of differential equations (1), which describes the motion of a plane-parallel combined sowing unit consisting of aggregated tractor and hooked up behind him fertilizer distributing drills that band-pass method makes fertilizers and suspended on her grain drill.

In this case, the obtained analytical dependence expressed in terms of generalized coordinates, and, consequently, the system of differential equations of motion (1) after substituting the expressions obtained it will be closed, which gives every reason for its numerical solution on the computer.

The results of the numerical solutions have the possibility to build a combined motion path points of the sowing unit depending on its design and the kinematic parameters, and thus to determine their values, which provide a large rectilinear trajectories sowing unit etc.

4. Conclusion

Compiled earlier system of differential equations of plane-parallel motion combined sowing unit is fully prepared. It can be used for numerical modelling that will enable to analytically determine the rational design and kinematic parameters that ensure its sustainable movement, and thus the quality of the implementation process.

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